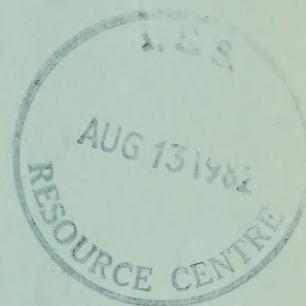


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RESILIENCE IN THE UNFORGIVING SOCIETY

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RESILIENCE IN THE UNFORGIVING SOCIETY

by

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INTRODUCTION

This series of Lindbergh lectures was born from a sense of crisis. It was designed to emphasize the need for a more harmonious view of man and his world. The concern arises from a sense of increasing vulnerability to risks, uncertainties, and unknowns. The labels are varied: vulnerability of global climate to increasing CO₂ concentrations; of ecosystems to increasing concentrations of organic and inorganic elements; of organisms and man to toxic substances new to evolutionary experience; of society to depletion and alienation of biological, land, mineral and energy resources. And as examples of Love Canal and Three-Mile Island incidents accumulate, the additional fear emerges of the simultaneous occurrence of independent crises from which society could not easily recover (Brown 1978).

Those labels, in an extreme form, lead some to demand a stop to growth and development. But others define their crises differently and see survival in continued growth and development. Just as we are vulnerable to resource and environmental crises, so are we vulnerable to social and economic ones; to unemployment and social inequities, to terrorism and war, to economic collapse, and to south/north disparities. Many argue that these instabilities can only be avoided by continued growth and accumulation and distribution of wealth for the betterment of all people and nations.

Brown (1978) argues cogently that these two sets of vulnerabilities are intertwined. Resource depletion and environmental degradation are in part the root of social and economic ills. And economic disparities generate further erosion of resource and environmental capital in a vicious cycle. The United Nations Environmental Program's espousal of "eco-development" reflects a middle path for the developing world that recognizes the intertwined nature of the problems. Growth is possible and needed, but it must be in harmony with man's natural endowment.

And yet the polarization between growth and no growth continues. It is the purpose of this paper to explore the roots of this polarization, to analyze the sources of crises and surprise in some specific examples of resource management and to suggest the ingredients needed for effective adaptation to surprise.

THE UNFORGIVING SOCIETY

Each of the polarities is driven by a common fear of the uncertain and unknown. One seeks for certitude by stopping the destruction and misuse of resources and environmental systems. The other seeks for certitude by continued growth and change in which the uncertainties are identified, reduced and controlled through application of improved knowledge and predictions. One argues that better regulation would provide better protection from the uncertain and unknown; the other that better prediction would lead to better design and control of the unexpected.

There is clearly the need for both regulation and prediction. There are profound hazards from erosion of biotic resources, from pollution and from toxic substances in the environment that require regulation. And who could argue that ignorance of the future is to be preferred to effective prediction? But the real questions are how to regulate and predict and how to live within the limits that our ignorance places on each.

The assessment and regulation of hazardous substances is a case in point. Clark (1980) makes a provocative comparison of risk assessment with witch-hunting during the several centuries spanning the Renaissance and Reformation. The parallels are uncomfortably close. Then, too, evil stalked the land. Crops rotted inexplicably, livestock succumbed for unknown causes, human disease and impotence were on the rise. Then, as now, there was a search for a generic cause to give reason for the unreasonable and hence a basis for action. They chose to ascribe these crises to witchcraft, and established a bureaucracy, the Inquisition, to identify, assess and regulate such hazards. And they developed tools and methods of enquiry with the same vigor as do modern day risk assessors. The harder they looked, the more witches they discovered and the more risks they revealed. Ever more stringent tortures were required because of the dangers of witches escaping detection. And ever more sensitive tests are now developed to detect the presence of hazardous substances and expose their short and long term dangers. Neither approach has a logical "stopping rule", a criterion that can clear a suspect unambiguously. Investigation ceases only with demonstration of guilt.

This regulatory urge rises as a testament to perceived failures. And that becomes a blunt necessity when directed to specific causes. Unlike witch hunting, the regulation of hazardous sub-

stances is indeed directed to specifics. Asbestos fibres do cause cancer. Radioactive material can kill. But even here there remains the profound regulator's dilemma: where to stop?

We encounter that issue frequently in working with agencies responsible for developing or regulating renewable resources. A dedicated regulator does not fulfill his charge by gaining more understanding but by forcing regulations. Faced with the need to protect an endangered fish species, an agency forced tertiary water treatment requirements when the real threat probably related to spawning and homing questions. An innovative search for the real causes becomes victim to the need to act decisively in high penalty public settings. It has led another agency to force cooling towers for electrical generation plants in order to reduce mortality of fish larvae caught in the cooling water. Again the regulator does not know, or wish to know, whether that affects the populations or not. Such an enquiry inevitably would lead to more uncertainty in the face of the natural variability of the environment. Certitude from action, however illusory, is to be preferred to ambiguity from understanding. And a polarized society is unforgiving of delayed decision.

But equally, prediction of uncertainties for better design and control faces a dilemma of ambiguity. The problem is that predictions are believable. Even the most counter-intuitive predictions of the systems analysts become believable once the causes of the prediction are described. It is believable that shifting energy production to coal (Häfele 1980) together with continued removal of forests (Woodwell *et al.* 1978) will release such masses of stored carbon that CO₂ concentrations will continue to rise in the atmosphere, thereby destabilizing the climate through the "greenhouse effect". But it is also believable that counteracting processes of carbon storage in vegetation and ocean will balance or slow that buildup (Kerr 1980), and that unrecognized cooling processes could, in any case, compensate for the warming effects (Madden and Ramanathan 1980). At the minimum, society thus would have the time to adapt and perhaps benefit from such changes. It is a tenet of science that predictions generated by hypotheses or models can only be disproved, not proved. But how can we establish a falsifiable proposition and experimental evidence for such global predictions?

We are forced to revert to developing a rigorous chain of logic in which the elements are subject to disproof but the whole is not. If enough people find that not merely believable but convincing, then action seems only prudent in the face of the costs of not acting. The actions include significant reversal of deforestation, energy conservation, development of energy sources not dependent on fossil fuels, and technologies

to isolate carbon production from the atmosphere. Such new policy directions and new technologies don't emerge overnight. Market penetration studies suggest a lead time of some 60 years. Since climatic destabilization could occur by that same time, that means decision and action now. But here is the trap. Once such a decision was made, the magnitude of the effort would foreclose the option of withdrawing from it if other, unexpected problems arose. And they would arise.

Hence prediction, as well as regulation, encounters the same dilemma. The predictions of crises that concern us often cannot be falsified. It is only the fertility of man's imagination that limits their generation. And the scale of response required to correct or ameliorate perceived crises has within it the seeds of generating new and larger ones in a setting where resilience and flexibility are lost.

If regulation and protection have no limit, and prediction and design are suspect, then society searches for scapegoats. The unforgiving society labels environmentalists as naive Utopians, businessmen as blindly greedy, academics as irrelevant parasites, politicians as venal and corrupt, and bureaucrats as blind tyrants. And there are good examples of each. But the search for enemies, while productive of examples, doesn't help.

Both the no growth and growth polarities smother innovation in the search for an illusory certitude. The environmentalist and accountant become partners. But real or perceived crises are not new to man. Nor is loss of trust. Man has always sailed on a sea of the unknown and somehow, haltingly, has prospered. His traditional method to deal with the unknown has been trial and error. Existing information is used to set up a trial. Any failures provide additional information to modify subsequent efforts. Success and failure are hence partners, for it is the failures that create the experience and understanding upon which new knowledge feeds. Both prehistoric man's discovery of fire and the scientist's development of hypotheses and experiments are in this tradition.

The success of this time-honored method, however, depends upon two minimum conditions. First, the experiment should not destroy the experimenter — or at least someone must be left to learn from it. The experimenter should be able to start again, having been humbled and enlightened by a failure. Instructive failures should be large enough to be perceived but small enough to open opportunities.

This first necessary condition is now being threatened. Our "trials" are capable of producing errors larger and more costly than individuals and society can afford.

(also would be better)
EIA

But there is a second condition that even precedes the appropriate design of a trial. The anthropologists and social psychologists tell us that man and societies deal with the frightening unknown by erecting myths. Myths provide guidance for man's actions and protect him from the frightening reality of the unknown. They allow him to dare to try. Myths can be as all-encompassing as the belief that there is a guiding spirit (nature or God) that will buffer us from evil and mischance. Or they can be as narrow as the belief that the free-market model will resolve all inequities. Myths are not wrong. They are partial truths. As Don Michael of the University of Michigan says, every individual and society must stand with feet planted firmly in mid-air. Action and trials then become possible. But in so doing, knowledge accumulates and the air under our feet becomes perceived. When that happens there is an active proliferation of competing myths as order is sought from confusion.

In many ways, the present polarization of the unforgiving society is a process of evolving new myths. And those alternatives determine the way we interpret reality and design our recipes for action. When the first pictures of Earth were obtained from space, many viewed them as a reconfirmation of the minuteness of man and the fragility of that globe floating in space. But an advertisement by the development arm of a major bank captioned the picture with "Businessmen, devour this planet." What was a fragile jewel for one myth became a digestible morsel for another. Reality is not perceived, it is conceived. And our myths provide the direction for those conceptions.

In the face of a battle between competing myths, perhaps it is fruitful to initiate a modest endeavor that explores the substance of alternative myths and the kinds of surprises and responses they generate. As a beginning, my colleagues and I at the Institute of Resource Ecology, University of British Columbia, in cooperation with the International Institute for Applied Systems Analysis, Austria, have begun to cross-compare a range of case studies of resource management to determine the qualitative properties of the natural system that generate surprises, the mismatch of the models and myths of management with those properties, and the response of the institutions when the surprise occurs.

THE ANATOMY OF SURPRISE — SOME CASE STUDIES

Five sets of problems have been examined in detail — forest pests, fisheries, forest-fire systems, savannah ecosystems and human disease. In total we have chosen twenty-six different examples for detailed analysis. Each was selected for its social or economic importance. Hence each has experienced a troubled and surprise-ridden management history that provides some insight into institutional responses. In addition, each is an ecological and environmental system where it is possible to mobilize and focus existing knowledge of causation.

In brief, our conclusions were that all the management policies succeeded in the short term; all failed in the longer term and produced a crisis; all owed the failure to a successful effort to reduce variability; and some adapted successfully to the failure while others did not.

- Successful suppression of spruce budworm populations in eastern Canada using insecticides certainly preserved the pulp and paper industry and employment in the short term by partially protecting the forest. But that policy has left the forest and the economy more vulnerable to an outbreak covering an area and of an intensity never experienced before (Clark, Jones and Holling 1979).

- Effective protection and enhancement of salmon spawning on the west coast of North America is leading to more predictable success. But because that triggers increased fishing and investment pressure, less productive stocks become extinct, leaving the fishing industry precariously dependent on a few enhanced stocks that are vulnerable to collapse (Larkin 1979).

- Forest fire suppression has been remarkably successful in reducing the probability of fire in the national parks of the United States. But the consequence has been the accumulation of fuel to produce fires of an extent and cost never experienced before (Holling 1979).

- Semi-arid savannah ecosystems have been turned to productive cattle grazing systems in the Sahel zone of Africa, southern and east Africa, the southern United States, northern India, and Australia. But because of changes in grass composition, an irreversible switch to woody vegetation becomes common and the systems become highly susceptible to collapse, often triggered by drought (Walker *et al.* 1979).

- Malarial eradication programs in Brazil, Egypt, Italy, and Greece have been brilliant examples of sophisticated understanding combined with a style of implementation that has all the character of a military campaign. But in other areas of the world, where malaria was neither marginal nor at low endemic levels, the transient success has led to human populations with little immunity, and mosquito vectors resistant to DDT. As a consequence, during the past five years some countries report a 30 to 40-fold increase compared to 1969-70, endangering not only the health of the population but also overall socio-economic development.

In each of these examples, the policy successfully reduced the probability of an event that was perceived as being socially or economically undesirable. Each was successful in its immediate, short term objective. Each resulted in the system evolving into one with qualitatively different properties. Spraying of budworm led to delayed tree mortality and incipient infestations spread over large areas. Salmon protection and enhancement led to more intense fishing and changed stock

composition. Fire suppression led to unnatural accumulations of fuel and changes in forest structure. Modern methods of cattle stocking and range management led to changed vegetation composition in the savannahs. Malarial control led to resistance of vectors to insecticides, and to populations whose immunity was lost.

These qualitative changes emerging from the successful reduction in the frequency of an event led to economic and social dependency on continuing success. The cost of failure multiplies as the probability of failure is reduced. And all these situations led to institutions whose goal and vested interest was to continue to implement the policy — to spray insects, to build hatcheries, to fight fires, to produce cattle, and to eradicate malaria. Hence retreat is extremely costly, is resisted, and alternative options are few.

But there are differences in the perception and response to these surprises. Some, like the malarial control program, accurately perceived these events as possible very early into the effort but took the gamble by emphasizing vigilance in control. Some simply lacked or ignored the information to anticipate the problem, but when it occurred responded adaptively with a change in policy. Fire control policies in United States national parks, for example, have now shifted to return fire as part of the natural system. Still others ultimately encountered the failure, resisted perceiving it, and persisted in the original policy in the face of their failure with retreat and adaptation becoming more and more difficult. That seems to be the case in budworm research and management in Canada.

Hence the fundamental question is not how to reduce failure simply by increasing protection by regulation or by increasing knowledge for prediction. That alone can generate bigger and more intractable failures. To regulation and prediction must be added adaptation. Regulation and prediction are needed responses to the known; adaptation is a needed response to the unknown and the unexpected. Regulation, prediction and adaptation are like the three legs of a stool, and like those legs, must be in balance with each other. But our science and our methods have largely concentrated on the first two, leaving adaptation to the intuitive reaction of individuals to unexpected events. Rarely does anyone suggest the generation of instructive surprises, probes into the unknown, as part of our designs. And when and where to do it is left to intuition in a vulnerable and unforgiving setting.

The studies described above are our first efforts to begin to clarify and organize an understanding of surprise and the responses to it. The key questions are what are the sources of surprise, which ones are most difficult to deal with, how do people and institutions interpret and respond to surprise, and how can we design and manage failure and surprise adaptively?

SOURCES AND CONCEPTIONS OF SURPRISE

Surprise occurs when our conceptions of reality do not match reality. Earlier I argued that those conceptions have their root in myths. And the myths that are relevant are those concerning the way systems respond to disturbance. Elsewhere (Holling 1978) I described four qualitatively different myths of stability, which provide a useful perspective to interpret our case study examples.

One of the simplest myths is one of global stability. That is, once any disturbance of any magnitude is removed the system returns to an equilibrium condition. This myth underlies many of the presumptions of economics with a focus on equilibrium and near equilibrium conditions. After all, the dominant property seems to be the final condition of rest or equilibrium, and any other behavior is transient and seems trivial. It is a comforting myth, for it represents a benign and infinitely forgiving nature. Trials and mistakes of any scale can be made in this world and the system will recover once the disturbance is removed. Since there are no penalties to size, only benefits of scale, this myth of Nature Benign comfortably and logically leads to "big is necessary" and centralization.

An opposing myth is that of instability. If the system is at some equilibrium, the slightest disturbance will lead to ultimate extinction of one or more variables. Since we know that systems persist, this myth of instability would seem to be impossible and uninteresting. Yet it has a rich tradition in philosophy and science. Persistence is conceivable if there is a diversity and fine spatial scale, so that as the variables in one locality are moving to extinction, they are reinstated from other localities that are in a different stage in their oscillation. This myth of Ephemeral Nature leads to a concentration on issues of spatial heterogeneity, diversity over space, and a fine-scale, local autonomy. It is in harmony with the persistent traditions of anarchism and of "small is beautiful". It is in complete opposition to "big is necessary", since any effort to increase size, to homogenize, will lead to collapse as the underlying instability of nature becomes obvious.

A third myth recognizes there can be more than one equilibrium with stability domains around these equilibria. That's the myth of Nature the Practical Joker. Management can be seen to be proceeding well until unexpected jumps to other stability regions can produce apparently qualitatively different and unexpected behavior. It leads to management approaches that attempt to identify undesirable and desirable ones. That is within the highly responsible tradition of engineering for safety, of nuclear safeguards, of environmental and health standards. It depends upon and presumes knowledge. The position of the stability boundaries must be known, the distance

to them must be continually monitored, and there must be effective remedial response if they come too close to the boundary. It is the myth that underwrites an exclusive interest in regulation and prediction. It works beautifully if the system is simple and known. But if the boundaries themselves are not known, then that management style leads to restricted variability and the possible movement of stability boundaries whose existence was not suspected. Surprise occurs because the standard settings and control have been so effective. Far from being resilient solutions, they seem to be the opposite. It emphasizes a fail-safe design at the price of a safe-fail one.

The final myth is rarely conceived, but it is the one that most closely matches the structure and behavior of the five sets of case studies. It is the myth of Nature Resilient. In this myth there is an emphasis both on the existence of a number of stability regions, which can shift and change, but, most important, that the form of those regions is determined by the past history of variability. It leads to designs that attempt to allow a system to adapt to and benefit from change, rather than controlling change. Hence resilience becomes the capability to adapt to surprise because of past experiences of instabilities. Such a myth would recognize the reality of the unknown and the ability to survive and benefit from "failures". It is even possible to develop skeletal models of institutions themselves, similar to those we have developed for natural and managed systems. Even the simplest representation (Holling, Huang and Vertinsky 1976) shows the same properties of multiple equilibria, shifting stability domains, and evolving parameter structure.

But we believe our present state of knowledge of institutions is such that the development of theory has a lesser priority than the development of careful case studies of resource and environmental management institutions and their cross-comparison. In the examples discussed here we do see two classes of response. Those institutions that have developed policies that induced a rhythm of change, with periods of innovation followed by consolidation and back again, seem to maintain a flexible and adaptive response to surprise. Expected problems and opportunities are detected and can be turned to benefits. Those institutions that have evolved toward stability, toward minimizing disturbances, toward being risk-averse, tend to react to problems and opportunities as crises. The adaptive response withers, and instead there is, paradoxically, an attempt to further reduce these uncomfortable intrusions. Options are rapidly foreclosed. It is the world of my earlier caricature of the environmentalist and accountant, of the no-growth and growth polarities.

INGREDIENTS FOR ADAPTIVE DESIGN

The best I can do at this stage of our studies is to summarize those key features in the examples analyzed, and others, that seem to be important for adaptive design.

• Some Designs are Forgiving of Error.

Two clear categories of "solution" appear when we compare our case studies. One class is unforgiving of error, one is forgiving. The use of insecticide to control insect populations in order to protect trees from defoliation or people from malaria requires a level of vigilance and efficiency of application that does not match well with the fallibility of man and his machines. In contrast, biological control, through the introduction of parasites, predators or diseases of pests, represents an effort to work through natural laws to introduce dynamic responses to change that are self-regulating, self-monitoring, and self-correcting. Failure can still occur but it is typically localized and transient — just sufficient and frequent enough to keep us alert and responsive.

The same categories are found in engineering designs. The DC-10 aircraft, for example, has had a troubled design history. One of the problems was associated with the latching device on the doors. The design was such that occasionally ground crew would not shut the door properly. In such cases, when the door opened at high altitude there was rapid decompression in the cabin. That then caused collapse of the floor separating cabin and lower storage areas because of pressure differences. This severed the control cables running through the floor, causing a number of crashes. Two distinct solutions were attempted. Commercial airlines emphasized redesign of the door latch, and "fail-safe" procedures for ground crew. The military, on the other hand, added a solution more forgiving of error by simply cutting holes in the floor so that pressures could be quickly equalized. Subsequent incidents of rapid decompression led to further crashes of commercial aircraft and controlled and successful emergency landings of military ones. The latter solution explicitly argues that the probability of failure can never be reduced to zero. They represent safe-fail solutions rather than fail-safe ones.

Freeman Dyson's description (1979) of the early days of nuclear power design provides another example. At that time, General Dynamics established four design teams, each with different strategic objectives. Dyson was associated with one directed by Edmund Teller who described the team's objective as achieving inherent safety. That is, the laws of physics would be used to prevent catastrophic excursions of the nuclear reaction rather than operating procedures and engineering devices dependent on fallible people and machines. The device was to be safe enough for a school to operate. They achieved that goal by designing the fuel rods so that the nuclear reaction would of itself be damped, even when the control rods were totally removed. Again it represents a solution forgiving of error, a solution that ultimately succumbed to the present schemes of fragile engineered safety as a consequence of premature cost-effectiveness and efficiency arguments.

The myth of Nature the Practical Joker underlies the solutions that are unforgiving of error. They presume that knowledge, monitoring and control are sufficiently efficient and invariant that systems can be kept well away from danger points. And they presume, above all, a static world that does not evolve into unexpected structures.

- Success Can Trigger Crises or Opportunities.

All the cases examined were successful in achieving their short-term objectives — maintaining employment in the face of imminent destruction of the forest from an insect outbreak; reducing the frequency of forest fires; increasing the populations of salmon; increasing meat production from cattle; and decreasing the incidence of malaria. But as a consequence of that success, each system evolved into a qualitatively different one.

That evolution took place in three areas. First, the social and economic environment changed. More pulp mills were built to exploit the protected spruce-balsam forests, more recreational demand was developed in the parks protected from fire, more efficient and extensive fisheries were developed to exploit salmon, more land was moved into cattle ranches on the savannahs, and more development was possible in those areas protected from malaria.

Second, the management agencies began to evolve. Effective operational agencies were formed to spray insects, fight fires, operate fish hatcheries, encourage cattle ranching, and reduce mosquito populations. And the objectives of those agencies naturally shifted from the original socio-economic objective to one that emphasized operational efficiency. Better and better aircraft, navigation and delivery systems to distribute insecticide. Better and better ways to detect fires and control them promptly.

These changes in the socio-economic environments and in the management institutions were generally perceived and were rightly applauded. But evolution occurred in a third area — the biophysical — whose consequence was not generally perceived. In these examples, success was achieved by reducing the variability of a target variable — the forest insect populations, the fire-frequency, the salmon numbers, the cattle stocking density, and the mosquito populations. As a consequence, features of the biophysical environment, which were typically implicitly viewed as constants, began to evolve and change to produce a system that was structurally different. Reduction of budworm populations to sustained moderate levels led to accumulation and persistence of foliage over larger and larger areas. Any relaxation of vigilance could then lead to an outbreak sometime, in a place where it could spread over enormous areas. Reduction of fire frequency led to accumulation of fuel and the closing of forest crowns so that what once were modest ground fires affecting limited areas and causing minor tree mortality, became catastrophic fires covering large areas and causing massive tree mortality. And similarly, increased numbers of salmon led to increase in size and

efficiency of fishing fleets; maintenance of moderate numbers of cattle led to changes in grass composition towards species more vulnerable to drought and errors of management; persistent reduction in mosquitoes led to gradual increases in the number of people susceptible to the diseases, and to mosquitoes resistant to insecticide. In short, the biophysical environment evolved to one that was more fragile, more dependent on vigilance and error-free management at a time when greater dependencies had developed in the socio-economic and institutional environment for continued success. That static myth of Nature the Practical Joker faces the reality of the dynamic, evolutionary myth of Nature Resilient.

I am not arguing against the desirability of maintaining and enhancing employment or of reducing the debilitating burden of disease as some kind of back-to-noble-nature fantasy. Nor am I even arguing for a blanket indictment of solutions that are unforgiving of error. At times that is all that is available. At times they should be used, but only as a way to buy time for the development of alternatives. The difficulty is that technological man is good at making such techniques successful in the short term. As a consequence, the need and motivation for the continued exploration of alternative objectives and policies succumbs to the simulacrum of success. When the inevitable crisis begins to be perceived, there is often no obvious direction to go except to continue as before but more rigorously, more efficiently, and with bigger budgets. Policy changes typically occur in the face of crises but only when there are clearly understood options available. Delays in developing those alternatives shrink the domain of attainable alternatives. Success of unforgiving solutions in the unforgiving society demands continual exploration of alternative objectives and alternative policies. Don't wait for them to fail.

- Exploratory Technology Enriches Options.

What is true for policy development is true for technological development. Many policies are built from available technology as well as from social and economic incentives and penalties. If appropriate alternative technologies are not available; policy change is difficult. As control of budworm using insecticide seemed to be successful, programs to develop biological control agents, pheromones, or even different harvesting methods withered. At the moment, there is no operational alternative to insecticide. The phase of technological development was frozen in the face of apparent success.

Dyson (1979) makes the same point for development of nuclear power. He points out that the effective technological developments proceed through trial-and-error generation and exploration of alternatives. He argues that this phase of exploration was foreclosed in nuclear power developments by a premature application of the accountants' criterion of cost-effectiveness. The very real possibilities for designs that are more forgiving of error at a more manageable scale were not realized as the

present technology became entrenched within government and industry. Rather than having the environmentalist join the accountant in a further smothering of innovation, it would seem more appropriate to increase dramatically the support for exploratory technology in critical areas of unforgiving technology.

● Time and Rates.

Nature Resilient emphasizes evolution in the face of structures that can generate sharp, discontinuous shifts of behavior as a consequence of slow, continuous changes in key variables. It is a view of the self-organizing universe of matter, life and societies (Jantsch 1980). As a consequence, time and rates of change are central for both understanding and the development of adaptive, self-organizing designs.

The analysis of the biophysical part of our case study examples included three sets of biological variables, each operating at different speeds. In the forest insect pest examples they were the insect and its associated natural enemies, the foliage and the trees. Their speed is roughly related to their generation times — one year for the insect, eight years for the foliage, and over sixty years for the trees. In the grassland grazing systems the variables, from fastest to slowest, were grasses, shrubs and herbivores. As management begins to restrict the variability of the target variable, parameters typically associated with slower variables begin to change. Foliage in the budworm system accumulates at fairly high levels spread more homogeneously over space; fuel in the fire example accumulates and the tree species composition begins to shift, leading to closure of the crowns; the variety of fish stocks begins to simplify as less productive natural stocks become extinct; the proportion of productive but vulnerable grasses to resistant grasses increases; and the number of people susceptible to malaria and mosquito resistance to insecticide increases. These represent changes in variables and supposed parameters that are intermediate between the fastest and slowest. These changes are mediated by competition or natural selective processes. It is these changes that lead to increased vulnerability of the systems to unexpected events.

The adaptive capability of a management design in part is determined by the rate at which these structural changes proceed, but only in relation to the rates of change of dependencies in the socio-economic environment and rate of change of the management institutions. We do not have enough examples to make a convincing generalization but there are suggestive observations which seem to make sense. We note, for example, that present forest fire policy in the National Parks of the U.S. west has recently changed radically to return fire as the natural "manager" of the forests. That rather dramatic adaptation was not made easily and it rested upon the existence of an alternative policy and of technologies to implement it, on a climate of understanding and on costs that were relatively modest compared to our other examples. But it might be equally important that the critical variable of fuel and forest tree composition changed at the slowest rate of all our examples. It was

some sixty years before the change became critical. I argue that the relevant time unit of change for a management institution is in the order of 20 to 30 years, the turnover rate of employees. As a consequence, by the time the problem became critical there was a new generation of experts and policy advisors who would be more willing to recognize failures of their predecessors than of their own. As well, the slowness of change allowed the accumulation of knowledge of the processes involved and the communication of that growing understanding to a wide range of actors.

In contrast, the changes in the budworm/forest system proceeded at a faster rate. Insecticide spraying began on a large scale in the mid-1950s with conditions of vulnerability building to a critical point by the early 1970s. In this case, that 15-20 year period was insufficient to accumulate and, most important, disseminate an understanding of the problem. Alternative policies or technologies were not developed and the parents of the original policies were still central actors and defenders of the past. Adaptive change has been an agonizing process that is only now showing signs of occurring.

None of the examples we chose provide examples of a rapid occurrence of crisis. When they happen I expect that they are triggered by effects outside the system, since evolutionary change towards fragility needs time. Some years ago, for example, England was faced with serious lowering of the water table as a consequence of a period of drought. A careful analysis of rainfall patterns suggested it would take many years for the water table to recharge. In the face of the serious impact of water shortage, the U.K. cabinet decided to begin a major water diversion scheme to bring water from the north. That winter was the winter of the heaviest rains on record, and the water table was recharged rapidly. The adaptive response was quick and easy — stop the water diversion scheme. And it was easy because insufficient time had passed to develop those dependencies and commitments of dollars and prestige that inhibit change.

I emphasize that there are insufficient examples to generalize with confidence. But tentatively these observations suggest that the problems that are most difficult to adapt to are those which appear 15-25 years after a policy is implemented. Adaptation is easier for problems that emerge more rapidly or more slowly. That suggestion, or alternatives that might emerge from a more extensive analysis, have importance for decisions and evaluation of developmental or policy proposals. First, the analysis suggests that one can identify key parameters and variables that trigger unexpected events. And second, even a rough idea of the rates of change of those properties suggests the balance appropriate for investments into prediction, regulation and adaptation.

Unexpected events that occur rapidly require an emphasis on predictive capability. Those in the intermediate range require emphasis on adaptive capability (development of alternative policies, exploratory technology, searches for forgiving

solutions). Those that occur slowly require an emphasis on monitoring and regulation. But in all instances a balance is required among the three.

The path leading out of the unforgiving society is neither the extreme of growth nor the extreme of no growth. The one emphasizes predictions and designs to reduce uncertainty and the unexpected. The other emphasizes regulation to achieve the same end. Alone, both are self-defeating. The path requires a balance between prediction and regulation, a balance that is added by including adaptation. Adaptation explicitly recognizes that failures and unexpected events are inevitable. The goal is to introduce the flexibility and capability to respond to those as challenges to the innovative spark in man, rather than as crises that smother that spark.

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